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on supine exercise thermoregulation**

Hutchinson, Teresa Marie, M.A.

San Jose State University, 1994

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Effect of 20° and 80° Foot-Down Water Immersion Deconditioning
on Supine Exercise Thermoregulation

A Thesis

Presented to

The Faculty of the Department of Human Performance
San Jose State University

in Partial Fulfillment
of the Requirements for the Degree
of Master of Arts

By

Teresa Marie Hutchinson

August 1994

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ABSTRACT

EFFECT OF 20° AND 80° FOOT-DOWN WATER IMMERSION DECONDITIONING ON SUPINE EXERCISE THERMOREGULATION

by Teresa Marie Hutchinson

The purpose of this study was to evaluate exercise thermoregulation following water immersion deconditioning at 20° (20-IM) and 80° (80-IM) foot-down angles and chair rest control (C). Six men mean ($\pm$ SE) 31 ($\pm$ 2) yrs, 175.9 ($\pm$ 3.2) cm, and 78.1 ($\pm$ 2.6) kg underwent 70 minutes of supine cycle ergometer exercise following six hours water immersion at 20-IM, 80-IM, and C. The diuresis was similar in the 20-IM and 80-IM. Rectal temperature was higher at minute 70 in both 20-IM and 80-IM ($p < .05$) vs. C. Heart rate (baseline) was higher ($p < .05$) in 80-IM vs. C and at minute 70 in both 20-IM and 80-IM ($p < .05$) vs. C. Forearm total blood flow at minute 70 was lower in the 80-IM vs. C ($p < .05$). Water immersion at two foot-down angles did not affect diuresis, but did alter the thermoregulatory responses post-immersion and during exercise that appeared to be greater following the 80-IM than the 20-IM.

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CHAPTER I

Introduction

As humans continue to spend more time in space it is imperative that we understand the mechanisms of the physiological adaptations that occur in microgravity. It is critical to understand and be able to control and/or ameliorate the adverse physiological changes that may affect an astronaut's physical performance in space. Blood volume and extracellular fluid volume should be maintained for optimal physical performance (Greenleaf, 1973). Biomedical results from Skylab show decreases in plasma volume (hypovolemia) and red cell mass, and fluid shifts from the lower to the upper body in astronauts during space flight (Johnson, Driscoll, & LeBlanc, 1977; Thornton, Hoffler, & Rummel, 1977). In addition, an astronaut performing extra-vehicular activity (EVA) has to work against the resistance of the space suit while performing tasks mainly using the upper body. The tasks during EVA may involve repeated high intensities and/or long durations where an astronaut may experience problems with fatigue and thermoregulation.

Water immersion to the neck is a method to simulate a weightless environment. Results from immersion studies have reported a diuresis (Greenleaf, Shvartz, & Keil, 1981),

decrease in plasma volume (Behn, Gauer, Kirsch, & Eckert, 1969; Boening, Ulmer, Meier, Skipka, & Stegemann, 1972; Greenleaf et al., 1981), and increase in central venous pressure (Arborelius, Ballidin, Lilja, & Lundgren, 1972). Immersion-induced diuresis results in hypovolemia and total body dehydration. It is probable that the hypovolemia and negative water balance in astronauts in flight is due in part to reduced fluid intake (Greenleaf, 1986). Exercising while dehydrated may cause an excessive increase in core temperature (Pitts, Johnson, & Consolazio, 1944). Core temperature at rest is increased by 0.5°C following water immersion as compared to a control and continues to remain significantly elevated paralleling the control during exercise (Greenleaf, Spaul, Kravik, Wong, & Elder, 1985). Diuresis-induced dehydration and hypovolemia may cause an elevation in core temperature at rest because circulatory adjustments may not have allowed optimal thermal conductance to the skin. Performance of exercise will compound the dehydrated subject's ability to maintain thermoregulation with the possible addition of reduced evaporative heat loss. Therefore, it is imperative to understand the circulatory adjustments that occur to accommodate the thermoregulatory needs following water immersion-induced deconditioning.

Statement of Purpose

The purpose of the experiment was to measure, evaluate, and compare exercise thermoregulation during supine exercise following water immersion induced deconditioning at 20° (20-IM) and 80° (80-IM) foot-down inclination and Chair Rest Control conditions. Measurements of core temperature, skin temperature, sweat rate, forearm total blood flow, cutaneous blood velocity, and tissue heat conductance during supine exercise were taken to better understand how immersion deconditioning and body orientation during immersion affect exercise thermoregulation.

Null Hypotheses

1. There will be no significant difference in indices of exercise thermoregulation with 20° foot-down inclination, 80° foot-down inclination water immersion angles, or Control conditions.
2. There will be no significant elevation in core temperature immediately following immersion in the 20° foot-down inclination angle immersion and the 80° foot-down inclination angle immersion.

Delimitations

This study was delimited to six, moderate-low trained, males, aged 27 to 39 years.

Limitations

The factors in this study which could not be controlled included the following:

1. The exact hydration status of the subjects upon entering the laboratory on each test day.
2. The long testing day and simulated environment which exists in a laboratory situation.
3. Water immersion only simulates a zero gravity environment.

Definitions

Dehydration is the process of fluid depletion from a normally hydrated state (euhydration) to a less than normal hydration state (hypohydration) (Greenleaf, 1979).

Diuresis is an increase in urine excretion to > 2ml/min.

Euhydration is an equilibrium state of normal body fluid volume levels (Greenleaf, 1979).

Hyperthermia is an abnormally high core (body) temperature or core temperature above approximately 38°C (Åstrand & Rodahl, 1986).

Hypohydration is a reduced body fluid volume from the euhydrated state (Greenleaf, 1979).

Peak Oxygen Consumption ($\dot{V}O_{2\text{peak}}$) is the highest oxygen uptake a subject can achieve during a given physical work test.

Skylab was the laboratory following Apollo where men worked in space for prolonged periods of time.

Thermoregulation is the process whereby the body maintains its core temperature.

CHAPTER II

Review of Literature

This review covers several topics: (a) circulation, heat stress, and hypohydration during exercise; (b) thermoregulation during exercise, heat stress, and hypohydration; and (c) forearm and cutaneous blood flow during exercise.

Circulation, Heat Stress, and Hypohydration During Exercise

Prior to and at the onset of exercise, changes in heart function and circulation are initiated from reflex activation of nervous impulses from levels above the medullary centers. From reciprocal innervation, a simultaneous increase in sympathetic activity occurs (Åstrand & Rodahl, 1986). The cardiac output increases (from the combined increases in heart rate and stroke volume) and tends to elevate blood pressure. A large portion of the increase in cardiac output goes to the active skeletal muscle via selective vasodilation, due to innervation by sympathetic cholinergic vasodilator fibers. Following the onset of exercise, sympathetic vasodilator activity ceases, but the increase in metabolism of active muscle releases metabolites which cause dilation of arterioles and capillaries. The sympathetic adrenergic vasoconstrictor fibers act to reduce blood flow to the skin,

kidneys, and splanchnic area. Essentially the blood shifts to the active muscles at a rate of about 2.2 liters/min from a maximal vasoconstriction of renal and splanchnic blood vessels (Rowell, 1974). Vasoconstriction in the non-working muscles and non-muscular areas helps to maintain a high arteriole pressure and direct the blood flow to the arterioles of working muscles. Dynamic, rhythmic activities such as cycling cause an alternate contraction and relaxation of the working muscles which helps to massage the blood vessels. This increases venous drainage from the muscles back to the heart and increases blood flow through the working muscles.

As exercise is prolonged, some of the blood volume shifts to the skin to transport heat for dissipation. Boulant (1981) states that the hypothalamus, at the base of the brain, governs blood flow to the skin and partially controls sweat secretion. When a subject is exposed to ambient heat greater than 28°C, the blood vessels of the skin dilate, venous return in the extremities occurs through superficial veins, and the heat conductance of the tissue increases (Åstrand & Rodahl, 1986). Suzuki (1980) concluded that changes in cardio-circulatory function, which limit a subject's performance in hot environments, were due to decreases in stroke volume resulting from decreases in the peripheral blood flow.

Decreases in splanchnic blood flow could accentuate the decreases seen in the peripheral flow.

Hypohydration tends to compound the circulatory changes that occur with heat stress and exercise. The resulting hypovolemia (Fortney, Nadel, Wenger, & Bove, 1981; Nadel, Fortney, & Wenger, 1980; Sawka, Francesconi, Pimental, & Pandolf, 1984) decreases exercise sweat rate (Fortney et al., 1981; Nadel et al., 1980) and reduces stroke volume and cardiac output (Nadel et al., 1980). Cutaneous blood flow eventually decreases in the attempt to maintain an already compromised venous return.

Thermoregulation During Exercise, Heat stress, and Hypohydration

Thermal centers in the hypothalamus partially regulate body temperature. How the mechanism works is unknown, but Cabanac (1975) concluded that the control system consists of a number of networks which operate independently of one another.

After approximately five minutes of exercise, core temperature begins to increase. The increase in core temperature is the main stimulus for sweat and skin circulation (Nielsen, 1986). The core temperature will continue to rise during exercise until equilibrium is reached at

approximately 60 minutes (Benedict & Cathcart, 1913). Rectal temperature and sweat rate increases in proportion to the work load (Nielsen, 1986). Greenleaf et al. (1985) have shown that with 70 minutes of supine exercise at 50% $\dot{V}O_{2peak}$, core temperature is elevated by 1.1°C. Core temperature at rest after water immersion was increased by 0.5°C and rose proportionally with the pre-immersion values. A decrease in sweat rate was not the cause of the post-immersion elevated core temperature during exercise because of the significant increases in sweat rate above the pre-immersion values.

Exercise in the heat causes greater increases in core temperature when compared with values obtained when exercising at an ambient temperature of 20°C. However, exercising when hypohydrated usually results in an excess elevation in core temperature and decrease in sweat rate. Pitts et al. (1944) demonstrated that the rise in exercise rectal temperature is proportional to hydration level. Therefore, if a subject exercises in a hot environment and becomes hypohydrated, the rise in rectal temperature will be greater than if water was consumed equal to sweat loss and euhydration was maintained. Other studies have confirmed the significantly higher elevations in rectal temperature when hypohydration was compared to euhydration or hyperhydration

(Ekblom, Greenleaf, Greenleaf, & Hermansen, 1970; Greenleaf & Castle, 1971; Senay, 1970).

Forearm (FBF) and Cutaneous (BFsk) Blood Flow During Exercise

A decrease in body fluid volume leads to a decrease in circulation to the skin, a higher temperature threshold for vasodilation, and a decrease in FBF as hypohydration and core temperature increase (Nadel et al., 1980). When subjects exercise in a hypohydrated state, FBF tends to increase initially as core temperature increases, but levels off and actually decreases at core temperatures above 38°C (Nadel et al., 1980; Nielsen, Rowell, & Bonde-Petersen, 1984). It appears that the decrease in blood volume due to hypohydration eventually results in decreased blood flow to the skin. This decreased flow occurs to provide sufficient blood flow to active muscles and the brain. Thus, supplying oxygen to the active muscles takes precedence over heat conductance to the skin for effective temperature regulation. If water replacement is not sufficient to maintain blood volume then body heat will not dissipate effectively, sweat rate will decrease, and core temperature will rise too high for the body to tolerate: the result may be heat exhaustion or sometimes heat stroke.

Forearm blood flow increases in the non-active muscles during supine and sitting ergometer leg exercise (Greenleaf, Montgomery, Brock, & Van Beaumont, 1979). The researchers also conclude that with heavy exercise there probably is no net transfer of blood from passive to active muscles, because blood flow increases in both the passive and active limbs. Lamb (1984) interprets the increase in FBF as an increase in muscle blood flow (MBF) in the forearm, because there appears to be skin vasoconstriction in the hand during bicycle exercise (Christensen & Nielsen, 1942).

The duration and intensity of exercise needs to be considered when determining blood flow distribution. With heavy exercise of short duration, vasodilation in the non-active forearm may occur immediately after the onset of exercise which would help dissipate the heat that develops in the working muscles. If this is true, then part of the increase in cardiac output ($\dot{Q}$) at the beginning of exercise may go to the periphery as well as to the muscles. Mack, Nose, Takamata, Okuna, and Morimoto (1994) report that there was a non-linear relationship between the increase in esophageal temperature (core) threshold for cutaneous vasodilation and exercise intensity. Their results indicate that a minimal exercise intensity (> 30% maximum oxygen consumption) was required to elicit a delay in active cutaneous vasodilation.

Zelis, Mason, and Braunwald (1969) in their investigation separated cutaneous and muscle forearm blood flow through iontophoresis of epinephrine into the skin of the forearm. They reported that with the initiation of exercise the skin blood flow decreased 47-74% and was greater than the 12-28% decrease in the muscle flow. Each of the responses were somewhat graded with the level of activity. Smolander, Saalo, and Korhonen (1991) also reported that the cutaneous vasoconstriction is generally graded with exercise level.

CHAPTER III

Procedures

Subjects

Six moderately fit, male subjects, age 27-39 years, were selected for the experiment. The subjects were apparently healthy, non-smokers who completed a comprehensive medical evaluation and provided informed consent. The comprehensive exam included a complete medical history, physical examination, and laboratory tests. The laboratory tests included a complete hematology (hemogram and differential); blood chemistry (Technicon SMAC2) including protein fractions, electrolytes, liver function, enzymes, lipid parameters, fasting glucose tolerance test; and macro and micro urinalysis. Additional tests included an electrocardiogram (ECG), and Bruce treadmill stress test. The protocol was approved by the San Jose State University Institutional Review Board: Human Subjects and NASA Ames Research Center HRERB. Informed consent was obtained from the subjects before data collection (see appendix).

Test Protocol

The experimental protocol consisted of three 6-hour sessions and a 70-minute post-session, supine leg exercise thermoregulation test. The 6-hour sessions consisted of a 20° foot-down inclination water immersion (20-IM), an 80° foot-down water immersion (80-IM), or chair rest (Control). The 20° angle was selected because it was the smallest angle that the body could be positioned on the stretcher and still have the water reach up to the neck and the 80° angle was used because it was the largest angle feasible within the constraints of the tank size. The two water immersion angles and chair rest control were randomly assigned and occurred on different days at least one week apart. All experiments were performed at approximately the same time of day in order to avoid variabilities due to the circadian rhythms.

Following the 6-hour sessions, but before the 70-minute exercise thermoregulation test, each subject underwent a LIDO isokinetic muscular strength and endurance test which lasted 35 minutes. Prior to any treatment session, peak oxygen consumption ($\dot{V}O_{2peak}$) was measured twice to obtain the highest values possible. Also, exercising in the laboratory familiarized the subjects with the environmental setting and the exercise task. The $\dot{V}O_{2peak}$ tests occurred over a two week period and concluded approximately one week before the

pre-immersion supine leg exercise test. No fluid was consumed during the 6-hour treatment, isokinetic testing, 20-minute baseline, exercise, or 20-minute recovery periods.

Peak Oxygen Uptake

Prior to each $\dot{V}O_2$ peak test each subject's weight, resting heart rate, and blood pressure were measured. The subject's height was taken before his first $\dot{V}O_2$ peak test. At least 2 days (and no more than 3 days) elapsed between each of the subject's $\dot{V}O_2$ peak test to allow for sufficient recovery. Environmental conditions were also assessed as appropriate.

Oxygen uptake was measured while the subject cycled on a horizontal Quinton electronic ergometer (model 845). Each subject warmed-up in the supine position at a load of 400 kg/m/min and then began to cycle at a load that was estimated to be 400 kg/m/min below their peak load (Greenleaf et al., 1988). The load then increased 200 kg/m/min every 2 minutes until the subject reported exhaustion or could not maintain the 70 rpm cadence (Greenleaf et al., 1988).

The instruments used were an Otis-McKerrow respiratory valve, a calibrated Pneumoscan (model S-300) electronic spirometer, and Applied Electrochemistry oxygen (model S-3A) and carbon dioxide (model CD-3A) gas analyzers. The gas analyzers were calibrated with a gas of known concentration

prior to each test. Expired air was drawn from the respiratory valve, passed over drierite, and analyzed for oxygen and carbon dioxide concentrations. A data acquisition system (Vista, Vacumed Co.) connected to an IBM AT personal computer calculated and printed respiratory quotient (RQ), pulmonary ventilation ($\dot{V}_E$) and oxygen consumption ($\dot{V}O_2$ in L/min and ml/kg/min) values every 15 seconds. The values recorded were the average values measured over the 15 second interval. Heart activity was monitored continuously with a Hewlett-Packard ECG unit (model 78203C) and a Gould (model 2400) chart recorder.

The usual criteria to determine a maximum test (R value greater than or equal to one, heart rate near the estimated maximum, and a $\dot{V}O_2$ plateau) were not used due to the fact that the tests occurred on a supine cycle ergometer which is a difficult position to exercise in and prevents subjects from reaching the aforementioned criteria. Therefore $\dot{V}O_{2peak}$ was defined as the highest value attained from the 2 tests; this value was the average of the last four data points during the last minute of the test where the subject was able to maintain 70 rpm on the cycle ergometer. The highest $\dot{V}O_{2peak}$ attained was used to determine the 50% exercise load.

Chair Rest Control

Each subject reported to the laboratory at 0600 hours, after an overnight fast. A light breakfast of fruit juice (600 ml), and toast and jam was consumed. At 0630 hours, the subject urinated and a nude body weight was measured. After the nude body weight was recorded, the subject rested sitting in a chair for a 45-minute control period. At 0720 hours the subject began the 6-hour chair rest control treatment. During the six hours the subject urine volumes were collected hourly as necessary and recorded. At the end of six hours the subject was transported, on a gurney, to the exercise room and underwent the LIDO isokinetic muscular strength and endurance test. Following the LIDO test the subject was transported via a gurney to the scale for a measurement of nude body weight. Then the subject was assisted on to the supine exercise ergometer and attached to the monitoring equipment for the exercise test.

Water Immersion

Each subject arrived at the laboratory at 0600 hours after an overnight fast. A light breakfast of fruit juice (600 ml) and toast and jam was consumed. At 0630 hours the subject urinated, inserted the rectal thermistor 16 cm beyond the anal sphincter to monitor core temperature during

immersion, then nude body weight was measured. Immediately following this, the subject rested sitting in a chair for a 45 minute control period. At 0720 hours the subject was assisted into the water immersion tank and supported with a plinth (stretcher) in thermoneutral tap water (35.0°C) up to the neck for 6 hours. During this the time subject urine volumes were collected and recorded as necessary. The subject was supported at either a 20° or 80° foot-down inclination. A water temperature of 35.0°C was used, because core temperature can be maintained at this temperature and thermoregulatory problems which may arise if the temperature is higher or lower than 35.0°C to 35.5°C (Beckman & Reeves, 1966; Craig & Dvorak, 1966; Reeves, 1966). An immersion of 6 hours was used to ensure that sufficient changes occurred in plasma volume, diuresis and body fluid shifts (Bowers, McCally, & Murray, 1966; Eckert, Kirsch, Behn, & Gauer, 1967). The subject was allowed to change position slightly in the tank and stand briefly once an hour to urinate. All urine volumes were collected and recorded. The monitoring of core temperature took place each hour throughout the 6 hour immersion. During water immersion an attendant was with the subject at all times and an overhead heater was used for subject comfort. At the end of the 6 hour immersion the subject urinated a final time. The subject was then assisted

from the tank quickly to a gurney and laid in the supine position in order to minimize the movement of body fluids. On the gurney the subject was dried and core temperature was monitored for 20 minutes. Following the monitoring of core temperature the subject underwent the LIDO isokinetic muscular strength and endurance test. The subject then was weighed nude and the weight loss during immersion represented the net respiratory and renal fluid loss. Following the nude body weight measurement the subject was assisted on to the supine exercise ergometer and attached to the monitoring equipment for the post-session exercise test.

70-Minute Supine Exercise Protocol

Prior to the submaximal exercise test, and while lying on the gurney, the subject dressed in shorts, sneakers, and socks. The subject was then positioned on the horizontal cycle ergometer, attached to the equipment (ECG electrodes, forearm total blood flow electrodes, laser Doppler probe, sweat capsules, and skin temperature thermistors), and rested for a 20 minute baseline control period. Immediately following the control period, the subject began to exercise at 50% of his $\dot{V}O_{2\text{peak}}$. Each subject exercised for 70 minutes, since at least 60 minutes of exercise are needed for core temperature to equilibrate which is important when measuring

thermoregulation indices (Benedict & Cathcart, 1913). A 20 minute recovery period followed the exercise period. Following the recovery period the subject towed off excess moisture and a final nude body weight was taken.

During the baseline, exercise, and recovery the following were measured and recorded at the given predetermined intervals. Every 5 minutes heart rate (HR), forearm blood flow (FBF), and air flow were measured. Every two minutes skin blood velocity (BF_{sk}), rectal temperature (T_{re}), local skin temperatures ($\bar{T}_{sk}$), and local sweat rates ($\dot{M}_{sw}$) measured from relative humidities and temperatures were assessed. Skin heat conductance (K_{sk}) was calculated once for each exercise test since subjects exercised at steady state; and $\dot{V}O_2$ was measured and recorded, as described in the peak oxygen uptake section, during the first 10 minutes of exercise. Dry bulb temperature, wet bulb temperature, relative humidity, and barometric pressure were measured prior to the 20 minute baseline control period.

Heart rate was monitored with a Hewlett-Packard model 78203C ECG unit and checked routinely by counting pulses. Yellow Spring Instrument Company series 700 thermistors on a Digitec model 2000 thermometry system were used to measure skin and rectal temperatures. Skin thermistors were placed on the lateral surface of the upper arm and forearm,

center lateral surface of the calf muscle, the middle lateral side of the thigh, and above the nipples of the right and left chest. The thermistors were held to the skin by thermistor holders.

Mean skin temperature ($\bar{T}_{sk}$) was calculated from the formula of Hardy and DuBois (1938): $\bar{T}_{sk}(^{\circ}\text{C}) = (0.06)(T_{\text{upper arm}}) + (0.13)(T_{\text{forearm}}) + (0.21)(T_{\text{calf}}) + (0.21)(T_{\text{thigh}}) + (0.20)(T_{\text{right chest}}) + (0.19)(T_{\text{left chest}})$. The constants for each of the segments represent the fraction of the surface area of the whole body accounted for by that body segment (Spaul, 1983).

Localized sweat rates were determined by passing dry air through a capsule attached to the skin (Spaul, 1983). The air temperature and water vapor in the airstream exiting the capsule were measured by resistance hygrometry and compared to the capsule supply side air humidity and temperature. The inlet air enters the side of the capsule tangentially, spirals around the inside of the capsule, and exits through the top center of the capsule. Thunder Scientific Corporation Resistance Hygrometers (model 2300H1T21) were used to measure the airstream for relative humidity and temperature. The values were recorded with a Digitec Data Logger (model 1100 Data Scan Sentinel). Airflow through the capsules was monitored continuously by in-line rotometers and a vacuum pressure gauge. In addition, airflow was calibrated prior to

the onset of the study and checked periodically throughout the duration of the study. The sweat capsules were placed, adjacent to the skin thermistors, on the upper arm, forearm, and calf.

The formula used to determine sweat rate from the measurements of relative humidity and temperature was contained in a computer program written by Spaul (1983):

$$\dot{M}_{sw}(\text{mg/cm}^2/\text{min}) = \frac{(\dot{V}_{ol}Q)[W_{out}-W_{in}]}{(SVA)(A_{sw})(0.06)} 60$$

Where:

$\dot{M}_{sw}$ = body water loss due to sweating

$\dot{V}_{ol} Q$ = rotometer volume flow rate, L/min

W_{out} = absolute humidity ratio leaving capsule (grams of water per grams of dry air)

W_{in} = absolute humidity ratio entering capsule (grams of water per grams of dry air)

SVA = specific volume of air (L/g, dry air), point of intersection between the mean control dry bulb and wet bulb temperatures obtained from a psychometric chart

A_{sw} = area under sweat capsule, 3.14 cm²

60 = 60 min/hr used to convert hours to minutes

0.06 = used to convert g/cm²/min to mg/cm²/min.

Total body sweat rate (g/hr) was estimated from the difference in nude body weight measured before and immediately after each experiment, corrected for respiratory weight loss (g/hr) (Mitchell, Nadel, & Stolwijk, 1972) and an insensible water loss of 25 g/hr (Benedict & Benedict, 1927).

Skin heat conductance (K_{sk}) is the ratio of the average heat flow to the skin surface, to the temperature gradient from the core to the skin surface. The formula used was a modified version (Greenleaf & Reese, 1980) of the basic equation by Winslow, Herrington, and Gagge (1937):

$$K_{sk}(\text{kcal/h/}^{\circ}\text{C/m}^2) = \frac{M_{\text{gross}} - E_{\text{res}} - C_{\text{res}} - W - (\pm S)}{A_b(\bar{X}T_{\text{re}60-70} - \bar{X}T_{\text{sk}60-70})}$$

Where:

M_{gross} = total heat production from oxygen intake in kcal/hr

E_{res} = evaporative heat loss from the respiratory tract ($0.58 \cdot$ respiratory water loss)

C_{res} = conductive-convective heat loss from the respiratory tract and assumed to be zero

W = heat loss due to external work ($0.86 \cdot$ exercise load in watts = kcal/hr)

$\pm S$ = change in body heat storage (kcal/hr) [$0.83 \times \text{wt}$ (0.8

$\Delta T_{\text{re}70-60} + 0.2 \Delta T_{\text{sk}70-60}) \times 60 \text{ min/hr}$], $\Delta T_{\text{re}70-60}$ = the

difference between T_{re70} and T_{re60} ($^{\circ}\text{C}$), and $\Delta T_{sk70-60}$ =

the difference between T_{sk70} and T_{sk60} ($^{\circ}\text{C}$)

A_b = body surface area in m^2 $[71.84 \times (\text{wt (kg)})^{0.425} \times \text{ht (cm)}^{0.725}]10^{-4}$

$\bar{X}T_{re60-70}$ = mean rectal temperature measured at 60, 62, 64, 66, 68, and 70 minutes of exercise ($^{\circ}\text{C}$)

$\bar{X}T_{sk60-70}$ = mean skin temperature measured at 60, 62, 64, 66, 68, and 70 minutes of exercise ($^{\circ}\text{C}$).

Respiratory water losses (RWL) was calculated from the formula of Ekblom, Greenleaf, Greenleaf, and Hermansen (1971):

$$\text{RWL (g/h)} = (\text{VEBTPS}) \times 60 [(e_{35} - e_{23}) (\text{rh})]$$

Where:

VEBTPS = expired volume of air (BTPS)

rh = relative humidity

e_{35} = saturated water density at 35°C

e_{23} = saturated water density at 23°C .

The measurement of oxygen uptake was performed with the techniques and equipment used for $\dot{V}\text{O}_{2\text{peak}}$.

The FBF was measured with a 2-channel, tetrapolar impedance plethysmograph (modified Beckman BR 100) by introducing a high frequency (approximately 100.4 kHz), low amperage (approximately 0.7 mA R.M.S.), constant current between two metallic electrodes placed just below the elbow and the mid forearm. Both arms were relaxed during the impedance measurements in order not to obstruct blood flow.

Total blood flow was calculated from the equation of Montgomery (1976):

$$\text{Flow(ml/100ml/min)} = \frac{16\pi L}{C^2} \times RkG_s \times \frac{25 \times 60 \times 100}{HR}$$

Where:

16 = correction for volume of limb segment

$\pi = 3.154$

L = distance between recording electrodes (cm)

$C^2 = 2[(C_2 \times C_2) + (C_3 \times C_3)]$, where C_2 and C_3 are circumferences at the two middle recording electrodes (cm)

R = blood conductivity (0.00015 mmho/mm)

k = instrument sensitivity (mmho/mm)

G_s = systolic pulse volume (mm). (the systolic pulse volume was measured after the experimental test day from the

arterial waveform recorded on the chart paper and was the intersection of systolic fall and base line to base line in millimeters)

HR = distance between 10 heart pulses on the recorder (cm)

25 = chart recorder velocity (mm/s)

60 = s/min

100 = conversion factor for flow to ml/100ml of limb volume

The distance between the recording electrodes and the circumference of the recording electrodes was measured with a cloth measuring tape. The cloth measuring tape was pulled snugly when measuring circumferences.

The LASERFLO blood perfusion monitor (TSI, model BPM 403) noninvasively measures capillary blood perfusion parameters (blood flow, volume, and velocity) in real time. The basic principle is the utilization of the Doppler shift of laser light backscattered from moving red blood cells in the cutaneous microcirculation (Holloway & Watkins, 1977). The probe head of the fiber optic cable directs laser light into the tissue, illuminating a volume of red blood cells and stationary tissue cells. Light energy (photons) is randomly scattered by both cell types. A portion of the scattered light is collected by multiple return fibers in the cable which are coupled to a photodetector in the blood perfusion monitor. The

photodetector converts the light into electronic signals and the blood perfusion monitor processes these signals to produce outputs proportional to blood flow, volume, and velocity. The signal recorded has been shown to be an isolated measurement of the cutaneous circulation because there is no contribution from blood flow in tissues deeper than 1.0 mm depth such as muscle and bone (Johnson, Taylor, Shepherd, & Park, 1984). The maximum Doppler frequency is 20 kHz and the maximum mean frequency is 8 kHz. The probe was positioned on the medial side of the forearm approximately 9 cm from the antecubital notch. An "X" was made with a permanent marker directly under the probe to ensure exact placement at each testing session. Electrode gel was placed on the probe and the probe was held in place with an adhesive disk. The probe was placed on the left forearm exclusively in order to prevent any monitoring equipment from interfering with the cutaneous circulation. The arm was relaxed throughout the entire experiment, supported at the shoulder, and positioned at heart level. The output from the LASERFLO blood perfusion monitor was recorded every 15 seconds through a data acquisition system (Vista, Vacumed Co.) to an IBM AT personal computer. Because flow cannot be directly measured blood velocity (BFsk) was used in all analysis.

Statistical Analysis

A multivariate analysis of variance with repeated measures was employed to determine statistically significant differences between the treatments and the exercise thermoregulation variables (forearm blood flow, forearm skin blood flow, rectal temperature, mean skin temperature, and sweat rates). The null hypothesis was rejected when $p < .05$. A one-way analysis of variance with repeated measures and a Student-Newman-Keuls post-hoc tests (rejected when $p < .05$) were used to determine significance between conditions of individual variables (i.e. environmental parameters, BW, Ksk, etc.), and paired-t tests (rejected when $p < .05$) were used to determine significance between time points of individual conditions.

CHAPTER IV

Results and Discussion

Introduction

This chapter includes the presentation and the discussion of the results.

Results

The MANOVA showed no significant differences between the three conditions in the measured variables.

Table 1 presents individual anthropometric and physiologic data for the six subjects. Their mean ($\pm$ SE) age, height, weight, and $\dot{V}O_{2peak}$ were 31 ($\pm$ 2) yrs, 175.9 ($\pm$ 3.2) cm, 78.1 ($\pm$ 2.6) kg, and 48 ($\pm$ 3) ml/kg/min, respectively. The (mean $\pm$ SE) values for the environmental parameters were dry bulb 23.4 ($\pm$ 0.1) $^{\circ}$ C; wet bulb 13.6 ($\pm$ 0.4) $^{\circ}$ C; relative humidity 29.4 ($\pm$ 2.3)%; barometric pressure 767.1 ($\pm$ 1.0) mmHg; and air flow 17.8 ($\pm$ 0.4) ft./min. There was no difference in the environmental parameters between the two water immersion and chair rest control conditions.

Table 2 presents the mean ($\pm$ SE) decrease in body weight during the 6-hour treatments, 70-minute post-treatment supine ergometer exercise, and total weight loss; urinary output during the 6-hour treatments; total sweat rate and

Table 1

Anthropometric and Physiologic Data

Subject no.	Age, yr	Height, cm	Weight, kg	Surface Area, m ²	$\dot{V}O_{2peak}^a$, L/min	$\dot{V}O_{2peak}^a$, ml/kg/min	70-min Exercise Load, watts
1	28	168.2	69.45	1.79	3.99	56	147
2	39	183.4	83.92	2.06	3.73	44	114
3	28	177.5	83.64	2.01	4.50	56	164
4	27	186.0	83.21	2.08	3.99	49	147
5	37	166.6	76.99	1.86	3.17	40	114
6	27	174.0	71.59	1.86	3.24	46	114
<u>M</u>	31	175.9	78.13	1.94	3.77	48	134
$\pm SE$	2	3.2	2.64	0.05	0.20	3	9

^a $\dot{V}O_2$ = Oxygen consumption.

Table 2

Mean ($\pm$ SE) Decrease In Body Weight (BW) During 6-Hour Treatments and 70-Minute Supine Ergometer Exercise: Total Decrease in Body Weight: Total Urinary Output During 6-Hour Treatments: Total Sweat Rate, and Tissue Heat Conductance During 70-Minute Supine Ergometer Exercise; and Heart Rate Minute 70 During 70-Minute Supine Ergometer Exercise.

	Control ^a		20-IM ^b		80-IM ^c	
Decrease BW 6-Hour (kg)	<u>M</u>	-0.69 (0.13)	<u>M</u>	-1.46* (0.15)	<u>M</u>	-1.58* (0.22)
Decrease BW 70-Minute (kg)	<u>M</u>	-0.78 (0.08)	<u>M</u>	-0.80 (0.09)	<u>M</u>	-0.90 (0.14)
Decrease BW Total (kg)	<u>M</u>	-1.46 (0.19)	<u>M</u>	-2.26* (0.20)	<u>M</u>	-2.47* (0.21)
Urinary Output (ml)	<u>M</u>	498 (90)	<u>M</u>	1,342* (122)	<u>M</u>	1,368* (167)
Total Sweat Rate (g/min)	<u>M</u>	10.50 (1.10)	<u>M</u>	10.90 (1.3)	<u>M</u>	12.20 (2.00)
Tissue Heat Conductance (kcal/m/hr/°C)	<u>M</u>	43.00 (4.00)	<u>M</u>	44.00 (5.00)	<u>M</u>	42.00 (5.00)
Heart Rate Minute 70 (beats/min)	<u>M</u>	123 (6)	<u>M</u>	133* (6)	<u>M</u>	138* (7)

^a Control = Chair rest control; ^b 20-IM = 20° water immersion; ^c 80-IM = 80° water immersion.

*significantly different from the control value $p < .05$.

tissue heat conductance during the 70-minute supine ergometer exercise and heart rate at minute 70 (end of exercise) of the 70-minute supine ergometer exercise. The subjects experienced a similar magnitude of weight loss (80-IM = -1.58 ± 0.22 kg and 20-IM = -1.46 ± 0.15 kg) following the two 6-hour water immersion treatments that were significantly different from ($p < .05$) 6-hour chair rest control (-0.69 ± 0.13 kg). However the weight loss was similar, in the three groups, following the 70-minute supine ergometer exercise. In addition, water immersion plus 70-minutes of supine ergometer exercise resulted in a greater total weight loss (80-IM = -2.47 ± 0.21 kg and 20-IM = -2.26 ± 0.20 kg) when compared to the 6-hour chair rest control plus 70-minute supine ergometer exercise (-1.46 ± 0.19 kg) ($p < .05$). The urinary output was the same following the two water immersion treatments, however the volume was greater (80-IM = 1,368 ml and 20-IM 1,342 ml) than the volume following the 6-hour chair rest control (498 ml) ($p < .05$). Total sweat rate (g/min) and tissue heat conductance (kcal/m²/hr/°C) were the same in all three conditions. The baseline heart rate (-5 min) prior to the 70-minute supine ergometer exercise test for the 80-IM was higher than the baseline heart rate for the chair rest control (68 ± 4 vs. 59 ± 2 beats/min, $p < .05$) and 20-IM (68 ± 4 vs. 60 ± 3 beats/min,

$p < .05$). In addition, exercise heart rate at minute 70 (end of exercise) was higher in the 80-IM than the Control (138 ± 7 vs. 123 ± 6 beats/min; $p < .05$) and higher in the 20-IM than the Control (133 ± 6 vs. 123 ± 6 beats/min, $p < .05$).

In the 20-IM treatment group, rectal temperature was $37.07 \pm 0.05^{\circ}\text{C}$ at the end of immersion and rose to 37.26 ± 0.08 ($p < .05$) over a 20 minute period. The 80-IM group had a similar rectal temperature increase, following immersion, over the same time period ($37.05 \pm 0.06^{\circ}\text{C}$ to $37.31 \pm 0.08^{\circ}\text{C}$, $p < .05$).

Figure 1 displays the mean ($\pm$ SE) rectal temperature response (a) and the change in rectal temperature (b) from time zero to 70 minutes of supine exercise in all three conditions. Rectal temperature was higher ($p < .05$) at minute 70 of exercise in both the 20-IM ($37.96 \pm 0.12^{\circ}\text{C}$) and 80-IM ($37.90 \pm 0.18^{\circ}\text{C}$) conditions when compared to the Control ($37.64 \pm 0.11^{\circ}\text{C}$). In addition, the rectal temperature in the two water immersion groups did not plateau, but continued to rise until the end of exercise (min 60 vs. min 70; $p < .05$). The Control response showed a plateau (min 60 vs. min 70; NS). In all three conditions (Control, 20-IM, and 80-IM) rectal temperature increased ($p < .05$) from the time zero value to the end of exercise at 70 minutes with increases of $+0.85^{\circ}\text{C}$ for Control, 1.03°C for 20-IM, and 0.96°C for 80-IM. The change in

Figure 1
Mean $\pm$ SE rectal temperature (a) and change in rectal temperature (b) from time 0 rectal temperature during 70 minutes supine ergometer exercise and 20 minutes supine recovery in the Control, 20-IM, and 80-IM treatment groups. (* $p < .05$, min. 0 vs. min. 70; † $p < .05$, 20-IM vs. Control and 80-IM vs. Control at min. 70; § $p < .05$, 20-IM and 80-IM min. 60 vs. min. 70).

rectal temperature during exercise was similar in all three treatments until minute 40 where there was a trend towards a greater increase in rectal temperature in the two water immersion treatments

Figure 2 displays the mean ($\pm$ SE) mean skin temperature (a) and change in mean skin temperature (b) from time zero during 70 minutes of supine exercise. The mean skin temperature decreased ($p < .05$) during the first four minutes of exercise in the Control and the two water immersion treatment groups, then increased (significant only in the Control, min. 4 vs. min. 30, $p < .05$) until minute 30, when it plateaued in all three conditions (min. 30 vs. min. 40, NS). There was no significant increase in mean skin temperature from time zero to the end of exercise in any of the three experiments. In addition, the change in mean skin temperature during exercise was not different for the three conditions.

Figure 3a displays the mean ($\pm$ SE) forearm total blood flow response and 3b the change in total forearm blood flow response from time zero during the 70-minute supine exercise test. In the 80-IM group the forearm total blood flow response during exercise rose during the first 20 minutes of exercise (min. 0, 5.96 ± 0.51 ml/100ml/min vs. min. 20, 16.31 ± 1.7 ,

Figure 2

Mean $\pm$ SE mean skin temperature (a) and change in skin temperature (b) from time 0 mean skin temperature during 70 minutes supine ergometer exercise and 20 minutes recovery in the Control, 20-IM, and 80-IM treatment groups. (* $p < .05$, min. 0 vs. min. 4; † $p < .05$, min. 4 vs. min. 30 in the Control group).

Figure 3

Mean $\pm$ SE forearm total blood flow (a) and change in forearm total blood flow (b) from time 0 forearm total blood flow during 70 minutes supine ergometer exercise and 20 minutes supine recovery in the Control, 20-IM, and 80-IM treatment groups. (* $p < .05$, 80-IM min. 0 vs. min. 20; † $p < .05$, Control vs. 80-IM; § $p < .05$ min. 0 vs. min. 70).

ml/100ml/min, $p < .05$) and then plateaued (min. 20 vs. min. 70, NS). The 80-IM FBF response was lower at the end of exercise when compared to the Control group (16.85 ± 0.63 ml/100ml/min vs. 22.47 ± 2.31 ml/100ml/min, $p < .05$). The 20-IM and Control group responses were similar. Forearm blood flow rose significantly from time zero to the end of exercise ($p < .05$). The change in forearm total blood flow response was similar to the absolute values for all three conditions.

The mean ($\pm$ SE) forearm cutaneous blood velocity response (a) and change in forearm cutaneous blood velocity (b) from time zero is portrayed in figure 4. The blood flow velocity did not change during the first 10 minutes of exercise in all three groups (min. 0 vs. min 10, NS), but then began to increase only in the Control (min. 10, 0.29 ± 0.03 Hz $\times 10^{-2}$ vs. min. 20, 0.47 ± 0.08 Hz $\times 10^{-2}$, $p < .05$) and 20-IM (min. 10, 0.37 ± 0.09 Hz $\times 10^{-2}$ vs. min. 20, 0.65 ± 0.18 Hz $\times 10^{-2}$, $p < .05$) groups. Interestingly, in the 80-IM group, blood flow velocity did not begin to increase until after 20 minutes of exercise (min. 10, 0.46 ± 0.09 Hz $\times 10^{-2}$ vs. min. 30, 0.75 ± 0.13 Hz $\times 10^{-2}$, $p < .05$). Cutaneous blood flow velocity was higher ($p < .05$) at the end of exercise in all three groups (Control: 0.86 ± 0.12 Hz $\times 10^{-2}$; 20-IM: 0.91 ± 0.16 Hz $\times 10^{-2}$; 80-IM: 0.85 ± 0.15 Hz $\times 10^{-2}$) when compared to the beginning of

Figure 4
Mean $\pm$ SE forearm cutaneous blood flow (a) and change in forearm cutaneous blood flow (b) from time 0 cutaneous blood flow during 70 minutes supine ergometer exercise and 20 minutes recovery in the Control, 20-IM, and 80-IM treatment groups. (* $p < .05$, min. 0 vs. min. 70; † $p < .05$, min. 10 vs. min. 20 in the Control and 20-IM groups; § $p < .05$, min. 10 vs. min. 30 in the 80-IM group).

Figure 5
Mean $\pm$ SE upperarm (a), forearm (b), and calf (c) sweat rates during 70 minutes supine ergometer exercise and 20 minutes recovery in the Control, 20-IM, and 80-IM treatment groups. (* $p < .05$, min. 0 vs. min. 70)

exercise (Control: $0.21 \pm 0.01 \text{ Hz} \times 10^{-2}$; 20-IM: $0.29 \pm 0.06 \text{ Hz} \times 10^{-2}$; 80-IM: $0.28 \pm 0.02 \text{ Hz} \times 10^{-2}$) ($p < .05$). The change in blood velocity during exercise was similar in the three conditions.

Figure 5 presents (a) upper arm sweat rate, (b) forearm sweat rate, (c) and calf sweat rate. There was no difference ($p > .05$) in sweating in the three treatment groups at either the upperarm and forearm which were non-active muscle sites nor at the calf which was the active muscle site. However, there was a trend (NS) toward greater forearm sweating during the last 30 minutes of exercise in the 20-IM and 80-IM groups versus the Control group. Sweating did increase during exercise at all three sites, in the three experiments at the end of exercise (min. 70) when compared to the beginning (min. 0) ($p < .05$).

Discussion

Total body water is divided into intracellular and extracellular compartments. The extracellular compartment is comprised of plasma fluid (intravascular) and interstitial fluid (extravascular). The extracellular compartment plays a continual dynamic role in its major influence over intracellular homeostasis. Head out water immersion in thermo-neutral water results in a fluid shift from the extravascular

space into the intravascular space due to the hydrostatic pressure of water on the skin which is then translated to body tissues. The overall general increase in mechanical pressure on connective tissue is proportional to the depth of immersion, and the pressure on the abdomen perturbs the homeostatic condition and causes a cephalad fluid shift (Tajima, Ogata, Miki, Enishi, & Shiraki, 1989) as well as compression of the thoracic cardiorespiratory structures (Greenleaf, 1984).

Diuresis and natriuresis are the result of head out water immersion as well as a decrease in plasma volume, negative water balance and reduction in red cell, interstitial fluid, and plasma volumes (Greenleaf et al., 1981). The hydrostatic pressure gradient increases by 22.4 mmHg for each 30.5 cm of water depth, and the reaction time and magnitude of many physiological responses are proportional to the depth of immersion (Epstein, Miller, & Schneider, 1974; Lange, Lange, Echt, Gauer, & Dannenberg, 1974). There was an approximately 67 mmHg difference in water depth between the 20-IM and 80-IM body positions. During a graded water immersion experiment, Norsk, Bonde-Petersen, and Warberg (1986) reported that the increased stroke volume and plasma volume were not dependent on the level of immersion when subjects are immersed deeper than the umbilicus, implying that the increased fraction of the plasma is derived from the lower

extremities. However, Tajima et al. (1989) observed an increased urine flow in legless subjects. Thus, it appears that the fluid shift to the cephalad circulation is the result of hydrostatic pressure in the torso as well as the lower extremities. In the present study, both body angles allowed for submersion deeper than the umbilicus, therefore the fluid shift to the cephalad circulation must have come from hydrostatic pressure in the torso as well as the lower extremities. However the urine flow was no different in the two body angles, suggesting that not all physiological responses were altered by the difference in depth of immersion.

During the 6 hours of immersion the rectal (core) temperature remained the same at $36.06 \pm 0.05^{\circ}\text{C}$. However, during a 20 minute period immediately following water immersion, the rectal temperature significantly increased 0.2°C in the 20-IM experiment and 0.3°C in the 80-IM experiment suggesting an alteration in thermoregulatory responses. The subjects were covered with blankets to prevent shivering and kept in the supine position to minimize fluid translocation, except for the approximately 30 seconds it took for the subjects to climb from the tank to the gurney. In addition, the rectal temperature was higher in the 20-IM and 80-IM at minute 70 when compared to the control. Greenleaf

et al. (1985) found a similar significant increase ($+0.5^{\circ}\text{C}$) in men following six hours of water immersion; this increase was maintained throughout 70 minutes of supine cycle ergometer exercise, but not during recovery. They were not able to determine the mechanism for the elevated temperature, but concluded that the postulated factor was functioning after immersion and during exercise.

Fortney, (1987) in her study of women (21-39 years) who underwent 12 days of horizontal bed rest, also observed an elevated core (esophageal) temperature (non-estrogen group = $+0.25^{\circ}\text{C}$, $p < .05$; estrogen group = $+0.3^{\circ}\text{C}$, $p < .05$). She suggested a cutaneous vasoconstrictor response which functioned to oppose blood pooling in the lower extremities as the reason for the elevated core temperatures immediately following bedrest. When the subjects sat up immediately following bedrest and just prior to the exercise test, blood may have pooled in the dependent body regions, which caused a vasoconstrictor response and impairment of cutaneous heat exchange. This same response may have occurred in our subjects upon standing and climbing from the water immersion tank to the gurney.

The assumption can be made that during exercise following water immersion, sweating and evaporative cooling from the skin would be reduced because of body dehydration.

The data show no difference in sweat rate, skin heat conductance, and mean skin temperature in either water immersion experiment or Control during the 70 minutes of supine cycle ergometer exercise. Greenleaf et al. (1985) reported a significant increase in sweat rate, and no difference in skin heat conductance or mean skin temperature. In a hypovolemic state, whether or not a decrease in sweat rate will occur may be dependent on the degree of stress imposed on the thermoregulatory system. Claremont, Costill, Fink, and VanHandel (1976) observed no change in sweat rate during exercise at 35% $\dot{V}O_2\text{max}$ following plasma volume reduction by diuretics. However, when subjects exercised at 65-70% of their $\dot{V}O_2\text{max}$ following plasma volume reduction by diuretics there was a resultant decrease in sweat rate. It therefore appears that the hypovolemia may only become significant in the regulation of sweat rate when the subject experiences severe thermoregulatory stress. The presence of an elevated core temperature observed in the 20-IM and 80-IM conditions, in addition to the elevated baseline heart rate in the 80-IM condition, with no difference in sweat rate between treatments, supports the conclusion that water immersion deconditioning did not inhibit sweating and evaporative cooling from the skin because of body dehydration. There are two possible reasons for the lack of difference in sweating;

(a) the exercise intensity was not high enough to elicit severe thermoregulatory stress, or (b) the range in individual $\dot{V}O_{2\text{peak}}$ values (40-56 ml/kg/min) and work loads (114-164 watts) and ability to tolerate exercise stress, was so variable it masked the sweating response differences.

Even though the Laser-Doppler method to measure cutaneous microvascular flow is a safe and non-invasive, there are certain limitations present when analyzing data. Of major importance, is that the flow values obtained do not represent actual flow units, but are expressed as voltage measurements. This occurs because the Laser-Doppler can only quantitate blood flow using a standard technique for calibration. The technique is site specific due to the varying capillaries in the skin below the probe at different locations and local variations in flow through the capillaries. Ambient temperature and emotional state of the subject can also cause flow variations and thus, variations should be minimized. With the knowledge of these limitations, the Laser-Doppler technique provides continuous, linear measurements that are extremely selective to the cutaneous layer directly under the probe and provides sensitive and accurate indications of microvascular flow changes in the skin (Johnson, 1990). The results indicated a trend towards a vasoconstriction by no change in forearm cutaneous blood velocity during the first

10 minutes of exercise which supports what other investigators have reported of a minimal exercise intensity of $> 30\% \dot{V}O_{2\max}$ was required to elicit a delay in active cutaneous vasodilation (Mack et al., 1994). Suggesting that the $50\% \dot{V}O_{2\text{peak}}$ at which the subjects exercised may have been marginal in eliciting significant vasoconstriction. The increase during the first 20 minutes of exercise that then plateaued and was lower at the end of exercise in forearm total blood flow response in the 80-IM condition when compared to the Control indicates that forearm muscle blood flow must have been compromised, since the cutaneous velocity increased throughout exercise most likely in response to the elevated core temperature.

In conclusion, head-out water immersion deconditioning altered thermoregulation immediately post immersion and during supine exercise. The foot-downward angle of the body at 20° or 80° did not result in differences in urinary output (diuresis) during immersion. However, the elevation in baseline heart rate that continued through exercise, the lower forearm total blood flow, delay in cutaneous vasodilation, and no increase in sweat rate responses to exercise in the 80-IM condition, suggests a greater alteration in thermoregulatory responses when compared to the 20-IM data.

CHAPTER V

Summary, Conclusions, and Recommendations

Introduction

This chapter contains information on the summary of the research, conclusions and recommendations.

The purpose of this study was to measure, evaluate, and compare exercise thermoregulation following water immersion induced deconditioning at 20° and 80° foot-down inclination angle.

Methodology of Study

The subjects for this study were six healthy, moderately fit males aged 27-39 years. Each subject underwent two 6-hour water immersion deconditioning treatments (20° angle and 80° angle) and a 6-hour chair rest control. Following the two treatments and the control session each subject underwent a 70-minute supine exercise test. The exercise was performed on a supine cycle ergometer with each subject exercising at a load corresponding to 50% of his individual peak $\dot{V}O_2$ L/min.

Laboratory measurements taken during the 70-minute exercise thermoregulation test at determined intervals included: aerobic work indices, core temperature, skin

temperatures, forearm blood flow, skin blood flow, and sweat rates. Skin heat conductance was calculated from data taken during the last 10 minutes of exercise in order to correspond with the core temperature plateau. Peak $\dot{V}O_2$ L/min was measured prior to any treatment or control sessions. Peak $\dot{V}O_2$ L/min and $\dot{V}O_2$ L/min during exercise were determined from the analysis of expired gas concentrations and volumes during each minute of an incremental supine leg ergometer test to voluntary exhaustion and during the first 10 minutes of the 70-minute exercise test, respectively.

Summary of Results

The six healthy male subjects had a mean ($\pm$ SE) age (31 ± 2 yrs), height (175.9 ± 3.2 cm), body weight (78.1 ± 2.6 kg), and $\dot{V}O_2$ peak (48 ± 3 ml/kg/min). The volume of urinary output (diuresis) was similar in the 20-IM ($1,342 \pm 122$ ml) and 80-IM ($1,368 \pm 167$ ml) experiments. Rectal (core) temperature was higher at 20 minutes post immersion when compared to end of immersion (20-IM = $37.07 \pm 0.05^\circ\text{C}$ vs. $37.26 \pm 0.08^\circ\text{C}$, $p < .05$; 80-IM = $37.05 \pm 0.06^\circ\text{C}$ vs. $37.3 \pm 0.08^\circ\text{C}$, $p < .05$). The rectal temperature was higher at minute 70 in the 20-IM ($p < .05$) and 80-IM ($p < .05$) when compared to the Control. Baseline heart rate was higher in 80-IM versus Control (68 ± 4 beats/min. vs. 59 ± 2 beats/min., $p < .05$). Total sweat rate was similar

between the 20-IM, 80-IM and Control experiments. Forearm total blood flow was lower at the end of exercise in the 80-IM when compare to Control (16.85 ± 0.63 ml/100ml/min. vs. 22.47 ± 2.31 ml/100ml/min., $p < .05$).

Conclusions

Within the limits of this study the following conclusions were made.

1. The angle of the body and subsequent differences in hydrostatic pressure of water on the skin during head-out water immersion deconditioning did not affect the amount of induced diuresis.
2. The results suggest that the greater angle of the body during head-out water immersion deconditioning (80-IM) may affect the alteration of thermoregulatory responses to a greater extent than the 20-IM experiment.

Recommendations

1. Evaluate the forearm cutaneous blood flow-rectal temperature slope and threshold.
2. Evaluate the forearm total blood flow-rectal temperature slope and threshold.

3. Conduct future head-out water immersion deconditioning experiments at 20° and 80° foot-down inclination followed by 70 minutes of supine ergometer exercise studies to evaluate blood and urine indices of dehydration at the two angles and further evaluation of the possible greater thermoregulatory alterations with the 80-IM experiment (measurements of blood pressure, cardiac output, $\dot{V}O_2$ during exercise, and exercise at a higher exercise intensity). Also attempt to have subjects with a smaller range of peak $\dot{V}O_2$ values.

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Study to Investigate the Effects of Water Immersion
Deconditioning on Exercise Thermoregulation

Statement of Informed Consent for Cardiorespiratory
Endurance, Water Immersion, and 70-minute Exercise.

Invitation to Participate

You are invited to participate in a study investigating the effects of water immersion deconditioning on exercise thermoregulation. This study will be conducted in the Human Physiology Laboratory at Ames Research Center, Moffett Field, California.

Basis for Selection

You have been selected as a participant because you are a healthy, non-smoking male age 18 to 40 years and moderately fit. Should you decide to participate you will undergo a medical evaluation. The comprehensive exam will include a complete medical history, physical examination, and laboratory tests. The laboratory tests include a complete hematology (hemogram and differential); blood chemistry (Technicon SMAC 2) including protein fractions, AIDS test, electrolytes, liver function, enzymes, lipid parameters, fasting glucose tolerance test; and macro and micro urinalysis. Additional tests include an electrocardiogram (ECG), resting spirometric pulmonary function test, chest x-ray, and Bruce treadmill stress test.

Purpose of the Study

The purpose of this experiment is to measure, evaluate, and compare exercise thermoregulation following water immersion induced deconditioning at 20° and 80° foot-down inclination. Measuring the changes in forearm blood flow, core temperature, skin temperature, heart rate, cardiac output, and $\dot{V}O_2$ during supine exercise is a way to understand how immersion deconditioning affects exercise thermoregulation.

Explanation of Procedures

Supine Leg Ergometry for Cardiorespiratory Endurance (approximately 45 minutes)

Your peak oxygen consumption will be determined from tests which will involve pedaling on a supine stationary ergometer at progressively increasing levels of resistance. Your expired air will be collected through a mouthpiece connected to rubber tubing. Your heart rate will be monitored by six electrodes attached to your chest. Following the measurements of resting heart rate and blood pressure you will begin pedaling at a load estimated to be $400 \text{ kg}\cdot\text{m}\cdot\text{min}^{-1}$ below your peak load at 60 rpm. The load will then increase slightly ($200 \text{ kg}\cdot\text{m}\cdot\text{min}^{-1}$ every 2 minutes) until you report exhaustion and can no longer continue at the required pace of 60 rpm. The test will end when you indicate that you no longer wish to continue or your response (heart function, respiration, and/or physical appearance) indicate that you should not continue or you have reached your maximal effort or the monitoring equipment fails. It is anticipated that the test will last 15 minutes. Following the completion of this test, the resistance will be reduced so that you can recover comfortably. You will continue to cool down until your heart rate is less than or equal to 120 b.p.m. Hand grips and shoulder braces will be utilized for stabilization during the peak test. You will participate in at least three peak tests over a two week period and spaced at least two days apart to insure adequate recovery.

Water Immersion

You will participate in two sessions of head-out water immersion at 20° and 80° foot-down inclination prior to each exercise session approximately one month apart. On the morning you arrive at the laboratory (following an overnight fast) you will consume a meal of fruit juice, toast and honey. We will then collect and measure your urine, weigh you, ask you to insert a rectal probe to monitor your core temperature,

and help you get situated in the immersion tank. You will be supported by a stretcher at the two different angles. If necessary you may move around slightly and stand briefly to urinate into a urinal. The water temperature will be thermoneutral at approximately 35.0°C to prevent fluctuations in your internal (core) temperature. At the end of 6 hours you will be asked to urinate a final time. You will then be assisted onto another stretcher, dried, weighed, and brought to the supine cycle ergometer for the exercise thermoregulation test.

70-minute Exercise

You will participate in three 70-minute exercise sessions on the supine cycle ergometer to measure your exercise thermoregulation. There will be one pre-immersion session and one each following the two immersion angles. You will position yourself supine on the horizontal cycle ergometer for a 20 minute pre-exercise control period. After the 20 minute period will begin to exercise at 60% of your Peak $\dot{V}O_2$ for a total of 70 minutes. A 20 minute recovery period will follow the exercise period. During the pre-exercise control, exercise, and recovery period the following will be measured and recorded at 5 minute intervals: heart rate (HR), blood pressure (BP), forearm blood flow (FBF), skin blood flow (BFsk), core temperature (T_{re}), skin temperature (T_{sk}), and skin heat conductance (Ksk). Measurements of cardiac output ($\dot{Q}$) and $\dot{V}O_2$ will be taken at approximately 20 minute intervals.

Risks and Discomforts

Cardiorespiratory Endurance

Some discomfort and dryness in mouth, throat, and chest as a result of the restricted breathing, may occur. You may feel light headed, fatigued, and slightly nauseous for a short time following this test. Also the discomforts commonly associated with exercise: sweating, increased heart rate, increased breathing rate, and elevated core temperature. Before the test some of the hair on your chest may be shaved

off for placement of the ECG electrodes. When you are at or near peak exercise you may experience abnormal blood pressure, fainting and/or dizziness, muscle fatigue or cramps, and abnormalities in heart rate. If abnormalities are detected in pulmonary function or electrocardiograph recordings you will be excluded from this investigation.

70-minute Exercise

You may experience general fatigue with increases in heart rate, sweating, breathing rate, and core temperature. Some discomfort and anxiety may occur from the attachment to the equipment. The rectal probe may initially be slightly uncomfortable.

Water Immersion

You may experience some general fatigue from the 6 hour water immersion. Initial discomfort from the rectal probe may occur. You may experience a slight feeling of confinement and possibly embarrassment when you have to urinate.

Benefits from Participation in the Study

You will benefit from this study by receiving feedback on your cardiorespiratory endurance characteristics. In addition, you will be helping the physiologists at Ames Research Center (NASA) further understand the physiological changes that occur from a simulated weightless environment.

Assurance of Confidentiality

The results of this investigation may be used for research publication and presentation. Your right to confidentiality will be protected unless your express consent is granted prior to the publication or presentation of the data.

Withdrawal from the Study

You may withdraw your consent and discontinue your participation in this study at any time (including during testing) without prejudice. You may also decline to answer any question or item on the health history questionnaire.

Testing will be supervised and conducted by Dr. John Greenleaf and Teresa Hutchinson, a graduate student. Certified CPR personnel will also be present during testing and a lifeguard will be present during the water immersion.

If you have any questions about the investigation now or during the testing, please feel free to ask. If additional questions come up later or in the case of emergency, call; Teresa Hutchinson (408) 245-3443 or Dr. Greenleaf (415) 694-6604. In the case of any complaints during or after testing, you may contact Dr. Serena Stanford, Associate Academic Vice President of Graduate Studies and Research, at (408) 924-2480.

Consent

By signing this form, you are agreeing that:

- (a) you have decided to participate in this study having read the information provided above;
- (b) you understand the discomforts and risks involved;
- (c) you understand you can withdraw at any time;
- (d) you understand that your name will be kept confidential except with your express consent.

NAME

DATE

WITNESS

DATE